## Q1.

This question is about the equilibrium

$$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g)$$

(a) State and explain the effect, if any, of a decrease in overall pressure on the equilibrium yield of $SO_3$

Effect _____

Explanation _____

_____

_____

**(3)**

(b) A 0.460 mol sample of $SO_2$ is mixed with a 0.250 mol sample of $O_2$ in a sealed container at a constant temperature.
When equilibrium is reached at a pressure of 215 kPa, the mixture contains 0.180 mol of $SO_3$

Calculate the partial pressure, in kPa, of $SO_2$ in this equilibrium mixture.

Partial pressure of $SO_2$ _____ kPa

**(4)**

(c) A different mixture of $SO_2$ and $O_2$ reaches equilibrium at a different temperature.

The table below shows the partial pressures of the gases at equilibrium.

| **Gas** | **Partial pressure / kPa** |
|---|---|
| $SO_2$ | $1.67 \times 10^2$ |
| $O_2$ | $1.02 \times 10^2$ |
| $SO_3$ | $1.85 \times 10^2$ |

Give an expression for the equilibrium constant ($K$p) for this reaction.

Calculate the value of the equilibrium constant for this reaction and give its units.

$K_p$

$K_p$ _____

Units _____

**(3)**

(d) What is the effect on the value of $K_p$ if the pressure of this equilibrium mixture is increased at a constant temperature?

$$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g)$$

Tick (✓) **one** box.

The value of $K_p$

increases. ☐

stays the same. ☐

decreases. ☐

**(1)**

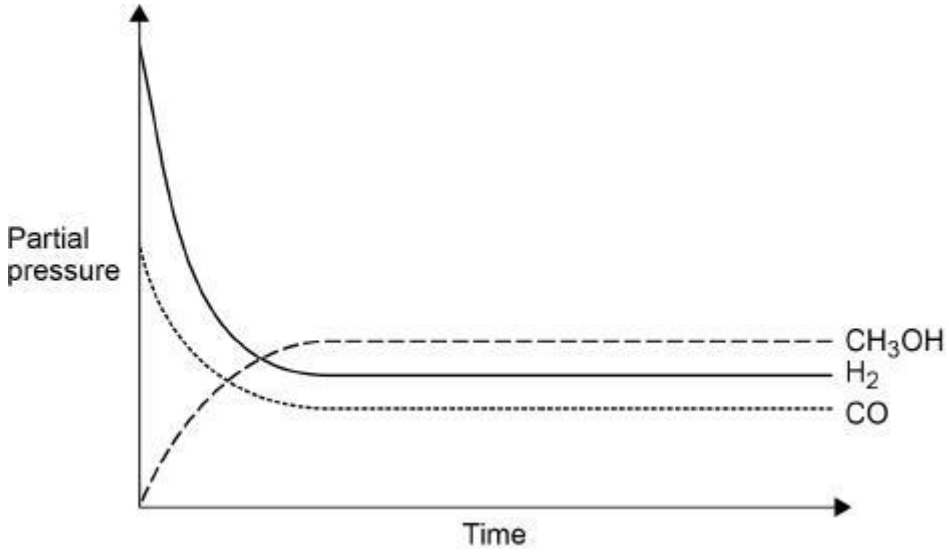
**(Total 11 marks)**

## Q2.

Methanol can be manufactured in a reversible reaction as shown.

$CO(g) + 2\ H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H^{\ominus} = -91\ kJ\ mol^{-1}$

The graph below shows how the partial pressures change with time at a constant temperature.




(a) Draw a cross (x) on the appropriate axis of the graph when the mixture reaches equilibrium.

**(1)**

(b) A 0.230 mol sample of carbon monoxide is mixed with hydrogen in a 1:2 mol ratio and allowed to reach equilibrium in a sealed flask at temperature *T*.
At equilibrium the mixture contains 0.120 mol of carbon monoxide.
The total pressure of this mixture is $1.04 \times 10^4$ kPa

Calculate the partial pressure, in kPa, of hydrogen in the equilibrium mixture.

Partial pressure of hydrogen _____ kPa

**(4)**

(c) Give an expression for the equilibrium constant ($K_p$) for this reaction.

State the units.

$K_p$

Units _____

**(2)**

(d) Some more carbon monoxide is added to the mixture in part (b). The new mixture is allowed to reach equilibrium at temperature *T*.

State the effect, if any, on the partial pressure of methanol and on the value of $K_p$

Effect on partial pressure of methanol _____

Effect on value of $K_p$ _____

**(2)**

(e) State the effect, if any, of the addition of a catalyst on the value of $K_p$ for this equilibrium.
Explain your answer.

Effect on value of $K_p$ _____

Explanation

_____

_____

_____

**(2)**

**(Total 11 marks)**

## Q3.

Sulfur trioxide decomposes on heating to form an equilibrium mixture containing sulfur dioxide and oxygen.

$$2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$$

(a) A sample of sulfur trioxide was heated and allowed to reach equilibrium at a given temperature.
The equilibrium mixture contained 6.08 g of sulfur dioxide.

Calculate the mass, in g, of oxygen gas in the equilibrium mixture.

Mass _____ g

**(2)**

(b) A different mass of sulfur trioxide was heated and allowed to reach equilibrium at 1050 K

$$2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$$

The amounts of each substance in the equilibrium mixture are shown in the table.

| **Substance** | **Amount at equilibrium / mol** |
|---|---|
| sulfur trioxide | 0.320 |
| sulfur dioxide | 1.20 |
| oxygen | 0.600 |

For this reaction at 1050 K the equilibrium constant, $K_p = 7.62 \times 10^5$ Pa

Calculate the mole fraction of each substance at equilibrium.
Give the expression for the equilibrium constant, $K_p$
Calculate the total pressure, in Pa, of this equilibrium mixture.

Mole fraction $SO_3$ _____

Mole fraction $SO_2$ _____

Mole fraction $O_2$ _____

$K_p$

Total pressure _____ Pa

**(4)**

(c) For this reaction at 1050 K the equilibrium constant, $K_p$ = 7.62 x $10^5$ Pa
For this reaction at 500 K the equilibrium constant, $K_p$ = 3.94 x $10^4$ Pa

Explain how this information can be used to deduce that the forward reaction is endothermic.

_____

_____

_____

_____

_____

_____

**(2)**

(d) Use data from part **(c)** to calculate the value of $K_p$, at 500 K, for the equilibrium represented by this equation.
Deduce the units of $K_p$

$$SO_3(g) \rightleftharpoons SO_2(g) + \tfrac{1}{2}O_2(g)$$

$K_p$ _____

Units _____

**(2)**

**(Total 10 marks)**

## Q4.

Nitrogen reacts with hydrogen in this exothermic reaction

$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g)$$

Which change increases the equilibrium yield of ammonia but has no effect on the value of the equilibrium constant $K_p$?

**A** Add a catalyst ⬭

**B** Increase the partial pressure of nitrogen ⬭

**C** Decrease the temperature ⬭

**D** Decrease the total pressure ⬭

**(Total 1 mark)**

## Q5.

Nitrogen and hydrogen were mixed in a 1:3 mole ratio and left to reach equilibrium in a flask at a temperature of 550 K. The equation for the reaction between nitrogen and hydrogen is shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(a) When equilibrium was reached, the total pressure in the flask was 150 kPa and the mole fraction of $NH_3(g)$ in the mixture was 0.80

Calculate the partial pressure of each gas in this equilibrium mixture.

Partial pressure of nitrogen _____ kPa

Partial pressure of hydrogen _____ kPa

Partial pressure of ammonia _____ kPa

**(3)**

(b) Give an expression for the equilibrium constant ($K_p$) for this reaction.

$K_p$

**(1)**

(c) In a different equilibrium mixture, under different conditions, the partial pressures of the gases are shown in the table.

| **Gas** | **Partial pressure / kPa** |
|---|---|
| $N_2$ | $1.20 \times 10^2$ |
| $H_2$ | $1.50 \times 10^2$ |
| $NH_3$ | $1.10 \times 10^3$ |

Calculate the value of the equilibrium constant ($K_p$) for this reaction and give its units.

$K_p$ _____ Units _____

**(2)**

(d) The enthalpy change for the reaction is –92 kJ mol$^{-1}$

State the effect, if any, of an increase in temperature on the value of $K_p$ for this reaction.
Justify your answer.

Effect on $K_p$ _____

Justification _____

_____

_____

_____

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**(3)**

**(Total 9 marks)**

## Q6.

Which statement about $K_p$ is correct for this reaction in the gas phase?

$$W + X + Y_2 \rightleftharpoons WXY + Y \qquad \Delta H = -46 \text{ kJ mol}^{-1}$$

**A** The value of $K_p$ is independent of pressure. ⬭

**B** The value of $K_p$ increases as pressure increases. ⬭

**C** The value of $K_p$ increases as temperature increases. ⬭

**D** The value of $K_p$ is independent of temperature. ⬭

**(Total 1 mark)**

## Q7.

Many chemical processes release waste products into the atmosphere. Scientists are developing new solid catalysts to convert more efficiently these emissions into useful products, such as fuels. One example is a catalyst to convert these emissions into methanol. The catalyst is thought to work by breaking a H–H bond.

An equation for this formation of methanol is given below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \quad \Delta H = -49 \text{ kJ mol}^{-1}$$

Some mean bond enthalpies are shown in the following table.

| **Bond** | C=O | C–H | C–O | O–H |
|---|---|---|---|---|
| **Mean bond enthalpy / kJ mol$^{-1}$** | 743 | 412 | 360 | 463 |

(a) Use the enthalpy change for the reaction and data from the table to calculate a value for the H–H bond enthalpy.

H–H bond enthalpy = _____ kJ mol$^{-1}$

**(3)**

(b) A data book value for the H–H bond enthalpy is 436 kJ mol$^{-1}$.

Suggest **one** reason why this value is different from your answer to part (a).

_____

_____

_____

**(1)**

(c) Suggest **one** environmental advantage of manufacturing methanol fuel by this reaction.

_____

_____

_____

**(1)**

(d) Use Le Chatelier's principle to justify why the reaction is carried out at a high pressure rather than at atmospheric pressure.

_____

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_____

**(3)**

(e) Suggest why the catalyst used in this process may become less efficient if the carbon dioxide and hydrogen contain impurities.

_____

_____

_____

**(1)**

(f) In a laboratory experiment to investigate the reaction shown in the equation below, 1.0 mol of carbon dioxide and 3.0 mol of hydrogen were sealed into a container. After the mixture had reached equilibrium, at a pressure of 500 kPa, the yield of methanol was 0.86 mol.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Calculate a value for $K_p$
Give your answer to the appropriate number of significant figures.
Give units with your answer.

$K_p$ = _____ Units = _____

**(7)**

**(Total 16 marks)**

## Q8.

Which change would alter the value of the equilibrium constant ($K_p$) for this reaction?

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

**A** Increasing the total pressure of the system. ⬭

**B** Increasing the concentration of sulfur trioxide. ⬭

**C** Increasing the concentration of sulfur dioxide. ⬭

**D** Increasing the temperature. ⬭

**(Total 1 mark)**